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**CONFIDENTIAL**  
May 3, 1960

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CONT RD-33) 25X1

VIA REGISTERED MAIL

[Redacted]

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Subject: Contract No. RD-33

Gentlemen:

We are pleased to enclose two copies of a proposal in response to your letter dated April 14, 1960. In the event you would wish us to undertake the program, we will be pleased to do so as a cost-plus-fixed-fee task order to our basic agreement with you.

We are also returning, as you requested, your April 14th letter and all attachments. If you have any questions about our proposal, please do not hesitate to contact the undersigned.

Very truly yours,

[Redacted]

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JAB:el

2 encls (proposal)  
2 encls (attachments)

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In regards to items (a) and (b) the following is a description of a proposed design of magnetic field and clamp-on current sensors for low frequency signals. Both types of sensors utilize the Hall effect in intermetallic semiconductors. A low-frequency magnetic-field sensor has been designed, capable of detecting fields below one microgauss.<sup>1, 2</sup>

As a result of this work, a magnetic-field sensor can be designed for frequencies down to 5 cps. This lower limit of frequency is due to the fact that a direct biasing current is used and the ohmic drop at the Hall terminals is blocked by a capacitor. Increasing the capacitor should reduce the lower frequency limit; however, the increase of excess noise in the amplifier reduces the sensitivity of the sensor. If an alternating biasing current is used instead, the Hall-output potential is shifted in frequency and can be amplified more conveniently. Using a regular envelope detector should restore the waveform of the original magnetic-field being measured. Although it seems that the use of alternating bias current should enable a similar measure of direct magnetic fields, it should be pointed out that because of the unusually high requirement on stability of the applied alternating current bias, the sensitivity of the steady magnetic-field measurement is diminished by a few orders of magnitude. This is because the relative change in the amplitude of the bias current causes a similar change in the Hall-output signal, as far as alternating magnetic fields are concerned, while for the case of the direct magnetic fields, such a change may be larger than the measured signal itself.

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<sup>1</sup> Epstein, M. and Schulz, R. B., "Magnetic-Field Pickup for Low-Frequency Radio-Interference Measuring Sets", 1959 IRE National Convention Record; p. 64.

<sup>2</sup> Epstein, M., Greenstein, L. J. and Sachs, H. M., "Principles and Applications of Hall-Effect Devices", Proc. National Electronics Conference, Vol. 15, 1959; p. 241.

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The magnetic-field measurement capability of a Hall-effect device can be used conveniently to measure currents in a conductor. The method of measuring the magnetic field around a current-carrying conductor has been utilized in the case of alternating currents using current transformers. The unique quality of the Hall effect to detect magnetic fields, both steady and alternating, is the basis for a so-called "clamp-on" ammeter. The sensitivity of such a device can be obtained as follows.

Let us assume a specimen of indium antimonide one thousandth of an inch thick. The semiconductor wafer is then placed in a gap of a toroid made of permeable material with relative permeability of 850. It is convenient to define an equivalent air-gap which is equal to the length of the actual air-gap plus the circumference of the toroid divided by the relative permeability. Therefore, the length of the equivalent air-gap, for a toroid one inch in diameter, is given by

$$d_{eg} = 0.001 + \frac{\pi}{850} = 0.0137 \text{ inch.}$$

Designating  $I_m$  as the current to be measured, the magnetic flux density in the air-gap is given by

$$B = \frac{\mu_o I_m}{d_{eg}} = \frac{4\pi \times 10^{-7} I_m}{0.0137 \times 2.54 \times 10^{-2}} = 3.6 \times 10^{-3} I_m \frac{\text{weber}}{\text{m}^2}.$$

From the work performed at the Foundation, for n-type indium antimonide with  $10^{16}$  carrier concentration at liquid nitrogen, it can be assumed that a biasing current of at least 0.25 amperes can be safely passed through a specimen one mil thick. The Hall coefficient, for this material, has been found to be  $R_H = 2.3 \times 10^{-4} \frac{\text{m}^3}{\text{Coulomb}}$ . Hence, the Hall-output potential is given by

$$V_H = \frac{R_H}{t} IB = \frac{2.3 \times 10^{-4} \times 0.25 \times 3.6 \times 10^{-3} I_m}{0.001 \times 2.54 \times 10^{-2}} = 8.15 \times 10^{13} I_m \text{ volts.}$$

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Therefore, the sensitivity can be defined as

$$S = \frac{V_H}{I_m} = 8.15 \times 10^{-3} \frac{\text{volts}}{\text{ampere}}.$$

Low input-impedance amplifiers are available to match the low resistance of the Hall-effect sensor, which are capable of measuring signals down to the thermal noise at its input. Assuming that the noise generated at the input does not exceed, on the average, five times the thermal noise,<sup>3, 4</sup> we obtain, for a Hall-effect sensor having a source resistance of one ohm, the open-circuit noise voltage generated in the frequency range of 3 kc, at room temperature,

$$V_N = 4kT\Delta f = 4 \times 1.38 \times 10^{-23} \times 300 \times 3 \times 10^3 \times 5 = 1.6 \times 10^{-8} \text{ volt.}$$

Thus, currents down to two microamperes can be detected over the frequency band of 3 kc. If narrow band filters are provided at the output of the amplifier, smaller currents, or the same currents with improved signal-to-noise ratios can be measured. In using a wide-band amplifier, in the manner indicated above, the currents in the frequency range of the amplifier can be read directly at the amplifier output, or displayed on an oscilloscope to represent its waveform.

The construction of the current meter in the form of a toroid around the conductor reduces considerably the pickup from external fields. It is of interest to note that the position of the current-carrying conductor with respect to the center of the toroid is not important. This

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<sup>3</sup> Oliver, D. J., "Current in Indium Antimonide", Proc. Phys. Soc. B., London, Vol. 70, pp. 331-332; March, 1957.

<sup>4</sup> Suits, G. H., Schmitz, W. D. and Terhune, R. W., "Excess Noise in In Sb", J. App. Phys., Vol. 27, p. 1385; November, 1956.

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follows from the fact that for materials with relative permeability  $\mu_r$ , the field in the gap depends mainly on the length of the gap, and is almost independent of either the length or the location of the high-permeability magnetic-reluctance path.

Our proposal for item (c) encompasses the designing, fabricating, and testing a dual-channel modulator playback system and modification of an Ampex Model 350 transport mechanism. Two estimates are given, one for (I), a dual-channel modulator system and modification of the transport for 1-7/8 and 3-3/4 IPS operation, and the second, for (II), development of L-shaped gap record and modulator playback heads with associated electronics and modification of the transport for operation at 1-7/8 and 3-3/4 inch per second. An alternative to the second estimate is (IIA) development of a dual-channel modulator system and modification of the transport for operation at 0.06 inch per second.

The two estimates are given for your consideration because of recent conversation with your representatives, indicating a desire for a total speed reduction, from record to final playback on the order of 1000 to 1. If this is to be done in two steps, that is, recording at 60 IPS and playback at 1-7/8 IPS and re-recording this reduced frequency signal at 60 IPS and again playing back at 1-7/8 IPS, effecting approximately a 1000 to 1 frequency reduction, the final recorded wavelengths of the low frequencies become several inches. The output of either a velocity or modulator type playback head approaches zero as the recorded wavelength increases beyond the head-to-tape contact length. It is therefore necessary to either accomplish the reduction in one step, thereby eliminating re-recording causing expansion of the wavelengths, or by employing L-shaped gap heads. An L-shaped gap head is a composite of a

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longitudinal-gap and transverse-gap head. This type head allows record and playback of signals down to and including zero frequency, which gives infinite wavelengths without reducing the high frequency capabilities of the system.

If extremely fine playback gaps (microgaps) are employed to meet the frequency response requirement of paragraph 2.9 in the specification, a fairly poor signal-to-noise ratio will result. If conventional quarter-mil gaps are used, an unequalized signal-to-noise ratio of 50 db can be obtained. Using equalization, the overall signal-to-noise ratio will drop to about 40 db and the system response will be flat within  $\pm 1.5$  db from 0.03 cps to 3500 cps at 3-3/4 IPS with the signal level down 12 db at 7000 cps. Some experimental work will be done to improve the signal-to-noise ratio and system response in an attempt to more closely meet your requirements.

It is believed all other requirements called for in Specification No. 60-A-1114-A can be met. Time and cost estimates for the three proposed systems are given on separate attached pages.

Brief monthly reports will be submitted describing progress, results of work carried on during the previous month, and plans for the next month's work. Upon completion of the program, operation and maintenance instruction manuals pertaining to the modifications made on the Ampex transport mechanism and the modulator playback system will be provided. Also, the modified Ampex Model 350 magnetic tape transport unit will be delivered equipped with a dual-channel modulator playback head and electronic auxiliaries. A spare dual-channel modulator head assembly will also be delivered. In the event the alternate approach is pursued, the modified transport will be delivered with special dual-channel

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L-shaped gap record and L-shaped gap modulator playback heads with record and playback electronic auxiliaries.

It is hoped this proposal fulfills your requirements and meets with your approval. We look forward to being of service to you and your staff.

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( A )

**Four Hall-Effect Magnetometers plus Two Amplifiers**

Option I - The sensitivity of the Hall-Effect Sensors should be of the order of one microgauss. The frequency response of the sensor should be from about 5 cps to 50 cps.

**TIME AND COST ESTIMATE**

It is estimated that 3 months will be required for performance of the research effort.

**Salaries:**

Engineer (1 man-month at \$850/mo. avg.)	\$ 850
Technician (1 man-month at \$500/mo. avg.)	500
Shop services labor (includes Drafting) 100 hours at \$3.60/hour	360
Salary related costs: (Employee insurance, F.I.C.A., vacations, and sick leave) estimated at 20%	<u>342</u>
Total direct salary costs	\$ 2,052
Overhead at actual cost, estimated at the approved Government bidding rate of 89%	\$ 1,826
Purchased expendable materials, supplies and services	\$ 500
Purchased general or special equipment	\$ 1,200
Long distance and telegraph	\$ 50
Report reproduction	\$ 50
Packing, crating and shipping charges	\$ 100
Fixed fee	<u>\$ 346</u>
Total Estimated Cost	\$ 6,124

### Development of a Hall-Effect Magnetometer

Option II - Utilizing alternating currents. The successful completion of this program should result in higher sensitivity of measuring alternating magnetic fields and the measurement of steady magnetic fields below 5 cps.

### TIME AND COST ESTIMATE

#### Salaries:

Engineering (3 man-months at \$850/mo. avg.)	\$ 2,550
Technician (3 man-months at \$500/mo. avg.)	1,500
Shop services labor (includes, Drafting) 300 hours at \$3.60/hour	1,080
Salary related costs: (Employee insurance, F.I.C.A., vacations, and sick leave) estimated at 20%	<u>1,026</u>
Total direct salary costs	\$ 6,156--
Overhead at actual cost, estimated at the approved Government bidding rate of 89%	\$ 5,479
Purchased expendable materials, supplies and services	\$ 1,000
Purchased general or special equipment	\$ 1,200
Long distance telephone and telegraph	\$ 50
Report reproduction	\$ 50
Packing, crating and shipping charges	\$ 100
Fixed fee	<u>\$ 842</u>
Total Estimated Cost	\$14,877

It is estimated that 6 months will be required for performance of the research effort.

( B )

Development of a "Clamp-On" Hall-Effect Sensor with one Amplifier. Sensitivity should approach 2 microamperes in a frequency range of 3 KC.



TIME AND COST ESTIMATE

Salaries:

Engineering (2 man-months at \$850/mo. avg.)	\$ 1,700
Technician (3 man-months at \$500/mo. avg.)	1,500
Shop services labor (includes drafting) 300 man hours at \$3.60/hour	1,080
Salary related costs: (Employee insurance, F.I.C.A., vacations, and sick leave) estimated at 20%	<u>856</u>
Total Salaries	\$ 5,136
Overhead at actual cost, estimated at the approved Government bidding rate of 89%	\$ 4,571
Purchased expendable materials, supplies and services	\$ 1,000
Purchased general or special equipment	\$ 600
Long distance telephone and telegraph	\$ 50
Report reproduction	\$ 50
Packing, crating and shipping charges	\$ 100
Fixed fee	<u>\$ 690</u>
Total Estimated Cost	\$12,197

It is estimated that 6 months will be required for performance of the research effort.

( C )

**I Dual Channel Modulator Playback System for 3 3/4 and 1 7/8 IPS****TIME AND COST ESTIMATE**

A program of 6 months duration is proposed for the design, development, construction and testing of a dual channel modulator system and modification of the tape transport mechanism for operation at 1 7/8 and 3 3/4 IPS. The engineering effort, and the resulting cost estimate considered to be necessary to adequately perform the work called for is outlined as follows:

**Salaries:**

Engineering (4 man-months at \$850/mo. avg.)	\$3,400
Technician (6 man-months at \$500/mo. avg.)	3,000
Shop (300 hours at \$3.60/hour)	1,080
Drafting (80 hours at \$3.60/hour)	288
Salary related costs: (Employee insurance, F.I.C.A., vacations, and sick leave) estimated at 20%	<u>1,554</u>
<b>Total Salaries</b>	<b>\$ 9,322</b>
Overhead at actual cost, estimated at 89%	8,296
Materials and Supplies	1,000
Travel	300
Long Distance Telephone and Telegraph	20
Report Reproduction	50
Fixed Fee	<u>1,134</u>
<b>Total Estimated Cost</b>	<b>\$20,122</b>

( C )

## II Dual Channel L-Gap Modulator Playback System for 3 3/4 and 1 7/8 IPS

or

 IIIA Dual Channel Modulator Playback System for 0.06 IPSTIME AND COST ESTIMATE

A 9 month program is proposed for the alternative scope involving either the L-shaped-gap heads or the modification of the transport for 0.06 IPS operation. The engineering effort, and the resulting cost estimate to be necessary to adequately perform the work called for is outlined as follows:

## Salaries:

Engineering (6 man-months at \$850/mo. avg.)	\$5,100
Technician (8 man-months at \$500/mo. avg.)	4,000
Shop (500 hours at \$3.60/hour)	1,800
Drafting (160 hours at \$3.60/hour)	576
Salary related costs: (Employee insurance, F.I.C.A., vacations, and sick leave) estimated at 20%	<u>2,295</u>
Total Salaries	\$13,771
Overhead at actual cost, estimated at 89%	12,256
Materials and Supplies	2,000
Travel	300
Long Distance and Telegraph	20
Report Reproduction	50
Fixed Fee	<u>1,703</u>
Total Estimated Cost	\$30,101